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THIRD-PARTY DAMAGE MONITORING: INTERNAL FIBER OPTIC INSTALLATION ON A TRANSMISSION PIPELINE USING A PIG, A DISENGAGEMENT SYSTEM AND A PACK-OFF HANGER

Carly Meena
SaskEnergy Incorporated & TransGas Limited
Regina, Saskatchewan, Canada

Neil Gulewicz
Hifi Engineering Incorporated
Calgary, Alberta, Canada

Carl Kennedy
Tundra Petroleum Services
Calgary, Alberta, Canada

Tim Collis
In-Line Pigging Solutions Limited
Calgary, Alberta, Canada

ABSTRACT

The risk associated with third-party damage to transmission pipelines in areas of urban development is high. Distributed monitoring is a modern technique that uses fiber optic cables as sensors to continuously monitor pipeline parameters such as acoustics, vibration, strain and temperature. The fiber optic system notifies the operator in real-time of ongoing events allowing decisions to be made to prevent external interference or quickly address an incident that has already occurred.

Traditional methods used to install distributed monitoring systems on pipelines have limitations and are not feasible for all transmission pipelines. For instance, it can be both challenging and expensive to trench in fiber optics in developed areas and other installation techniques require the pipeline to be temporarily taken out of service. SaskEnergy Incorporated's transmission line subsidiary, TransGas Limited partnered with a Canadian pipeline monitoring service provider to install fiber optics inside of a natural gas transmission pipeline using a pig, steel capillary tubing and a pack-off hanger. A disengagement system was incorporated to release the fiber optics after the desired monitoring distance was reached.

It was decided to perform the pilot project on a newly constructed NPS 6 natural gas transmission pipeline located in Humboldt, Saskatchewan. Nitrogen was used as a medium to simulate an in-service pipeline in order to reduce the risks associated with the first attempt of the project designs. The fiber optics were inserted into steel capillary tubing and connected to a disengagement system located at the back of a pig. A pack-off hanger was used to maintain pipeline pressure during and after the installation was completed. The spool holding the steel capillary tubing was stopped once the maximum monitoring distance was reached and the differential pressure activated the disengagement system located at the back of the pig. The pig continued to the receive location and the fiber optics remained in the pipeline for continuous monitoring. The deployment was successful and the fiber optics will remain in the pipeline for a one (1) year monitoring period.

The primary limitation to this pilot project was the strength of the steel capillary tubing. The steel capillary tubing's ultimate tensile strength would have to be higher to accommodate a pipeline with a larger outside diameter, multiple bends, large changes in wall thickness or large elevation changes. In addition, the steel capillary tubing must be removed from the pipeline in order to perform pigging activities.

1. INTRODUCTION

Transmission pipelines that travel through areas of development can be at a higher risk for third-party damage. Mechanical equipment that comes into contact with a pipeline can result in coating damage, gouging, or even a pipeline rupture. The consequence of a transmission pipeline rupture in a Class 3 location is high as it could result in injuries or fatalities. It is important to monitor pipeline right of ways (RoWs) to prevent third-party damage from occurring and to quickly address third-party damage that has occurred.

Traditional techniques used for monitoring pipeline RoWs may include aerial or ground patrols. A more modern and developing method is distributed monitoring. Distributed monitoring uses fiber optic cables to measure parameters such as acoustics, vibration, strain and temperature along a pipeline. Data collected by the fiber optic cables are sent to an interrogator that sorts through the data to notify the operator in real-time of alarming events that have occurred.

Fiber optic cables are commonly loaded into plastic conduit and placed on or near a pipeline at the time of the pipeline's construction. In cases where the pipeline has already been constructed and an area of development has expanded onto the pipeline's RoW, it can be both challenging and expensive to trench in the fiber optics at a later date. Another method is to pull the conduit through the pipeline using mechanical equipment but this method must also be performed at the time of construction or the pipeline has to be taken out of service for the installation.

Methods used to deploy fiber optic technology in down-hole applications were referenced for this pilot project. Being able to perform the installation while the pipeline was in-service would be an advantage to reduce the impact to system operations. It was decided to perform the installation using a pig, steel capillary tubing and a pack-off hanger. Another consideration was that only a portion of a pipeline may travel through a Class 3 location and benefit from distributed monitoring. Fiber optics are expensive so reducing the amount required to monitor a particular area would be beneficial. It was decided to incorporate a disengagement system so that the pig would release the fiber optics once the maximum desired monitoring distance was reached.

2. APPROACH & METHODOLOGY

It was planned to insert the fiber optic cables into steel capillary tubing and connect the tubing to a disengagement system located at the back of a pig. The pig would pull the steel capillary tubing into the pipeline using line flow. The steel capillary tubing would be held on a spool on an injection unit and a brake would be applied to the spool once the pig reached the desired monitoring distance. Differential pressure would build on the pig and activate the disengagement system allowing the pig to travel to the receive site and the fiber optics to remain in the pipeline for remote monitoring. A pack-off hanger would be used to maintain pressure within the pipeline during the steel capillary tubing installation. The pack-off hanger would also maintain pipeline pressure after the installation as the steel capillary tubing would have to exit the pipeline to connect to the interrogator and monitoring network at the launch site.

2.1 Location

There were several pipelines considered for this pilot project. Each of these pipelines travel through Class 3 locations with either ongoing or future plans for housing and business development. An important criteria considered in choosing a pipeline was the risk associated with a temporary outage if the pilot project were to fail. For example, if the pig lost centralization during the installation then it could get stuck in the pipeline. TransGas Limited considered building or renting a pipe circuit to test the project designs before attempting them on their pipeline system but it was decided not to proceed with this option as the associated costs were high.

Next, the designs of each pipeline were considered to evaluate their ability to accommodate a controlled pig run. Maintaining control of the pig speed would be important to ensure that the strength of the steel capillary tubing was not exceeded during the installation. A controlled pig speed would also be important to ensure that the disengagement system wasn't activated prior to the desired end distance. Pipeline designs considered as a part of the criteria included bends, wall thicknesses, transitions and elevation changes.

Bends were considered as a part of this criteria as pigs can have difficulty navigating those with a tight radius. Multiple back-to-back bends or those in close proximity were a concern as this could increase the frictional forces on the steel capillary tubing and result in an early activation of the disengagement system. Large changes in wall thickness and elevation are challenging for pigging operations in gas systems because the pigs are more likely to stop, slow down or over speed.

It was decided to perform the pilot project on an NPS 6 sweet natural gas transmission pipeline planned for construction in December 2019 in Humboldt, Saskatchewan. The NPS 6, 1.5 km (4,921 ft) pipeline was planned to replace an older NPS 4 pipeline that the city of Humboldt has plans to expand onto. In Figure 1 below, the light blue and green line segments show the route for the NPS 6, 1.5 km pipeline. The red box shows the area that the city of Humboldt plans to expand onto. The green line segment in Figure 1 represents the 800 m (2,625 ft) portion of the 1.5 km pipeline that would benefit from distributed monitoring for third-party damage.

FIGURE 1: HUMBOLDT FUTURE DEVELOPMENT PLANS

The designs for the NPS 6, 1.5 km pipeline would be able to accommodate a controlled pig run. The pipeline would have four (4) 45º bends and one (1) 90º bend. Each bend would have a minimum bend radius of 5 times the outside diameter which would be wide enough to allow the pig to travel smoothly. The maximum wall thickness change would be 0.6 mm (0.02 inch) throughout the pipeline and the elevation profile would be consistent without any changes greater than 2 m (6.6 ft). Lastly, the pipeline could be pressurized and used to simulate an already in-service pipeline for the pilot project before actually putting the pipeline into service. This would minimize the risk of a failed installation to system operations and still validate the designs in this pilot project for other in-service pipelines.

2.2 Designs

2.2.1 Pig Launcher and Pack-Off Hanger Attachment

A pig launcher was designed and constructed for the purposes of this pilot project. The nominal barrel was designed to bolt up to the NPS 6 Humboldt pipeline's full port isolation ball valve. An NPS 1 equalizer line was included to allow control over the differential pressure between the nominal and oversize barrels. A nipple was added to the nominal and oversize barrel to allow pressure readings to be taken throughout the installation. Two (2) NPS 4 kicker tees were added to route gas behind the pig for the installation. The total barrel length was just over 2 m (6.6 ft).

The pack-off hanger attachment was designed to bolt up to the oversize flange on the pig barrel. Two (2) 22.5º elbows were included to gradually bring the NPS 2 piping up 45º from the horizontal. The purpose of this design was to minimize the bending that the steel capillary tubing would experience during the installation. The pack-off hanger connected to the NPS 2 flange at the end of the pack-off hanger attachment. Figure 2 shows the pig launcher and the pack-off hanger attachment.

FIGURE 2: PIG LAUNCHER AND PACK-OFF HANGER ATTACHMENT

2.2.2 Pack-Off Hanger

An oilfield service provider that specializes in custom capillary injection solutions was brought onto the pilot project. As shown in Figure 3, the steel capillary tubing would be injected through the top of the pack-off hanger and into the pigging launcher. The pack-off hanger was designed to have two (2) sealing elements so that if one failed, another would be present to maintain pipeline pressure during the installation. Once the installation was complete, carbon steel slips and a thread protector would be added to the top of the pack-off hanger to keep the capillary tubing in place and ensure that the NPS 6 pipeline would maintain pressure once put into service.

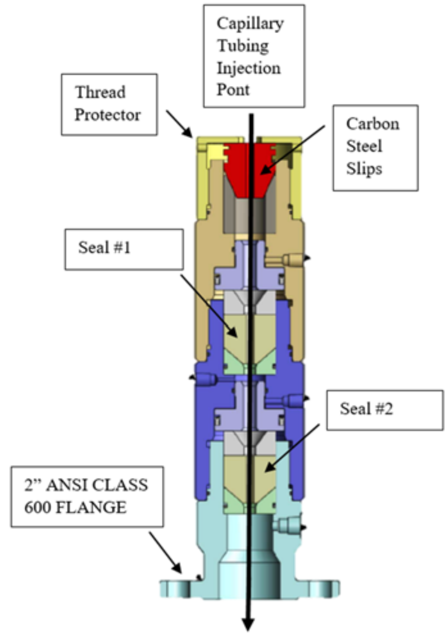

FIGURE 3: PACK-OFF HANGER

2.2.3 Gaseous Medium

A gaseous medium would be required for the pilot project to simulate a pipeline that was in-service. Natural gas, air and nitrogen were considered as primary options. The pipeline construction crew would have to perform methanol runs to dry the pipeline prior to the fiber optic installation because pig runs would not be possible after the installation was complete. This meant that an air dryer would be required to use air as a medium increasing the overall cost. Natural gas could be used for the pilot project by creating a loop between the existing NPS 4 pipeline and the new NPS 6 pipeline. However, a flare would be required at the receive site to achieve the flows required for the installation. The additional costs associated with using natural gas or air as a medium offset the costs to use nitrogen. Nitrogen was ultimately selected as the medium as it wouldn't impact the dew point of the newly constructed pipeline and could be finely controlled during the installation. Pigging in a low pressure/low flow operational envelope is challenging and flow control to manage the operation of the installation would be a key element to project success. From a safety standpoint, nitrogen had the lowest risk because it is an inert gas that displaces oxygen and prevents explosions from occurring. Although the risk of an explosion occurring due to the pilot project was considered unlikely, the designs for the project were unproven so it was decided to proceed with nitrogen for the installation.

2.2.4 Steel Capillary Tubing

6.35 mm (0.25 inch) 2205 alloy stainless steel capillary tubing was sourced for this pilot project. The yield strength of the steel capillary tubing was 551.6 MPa (80 ksi) and the ultimate tensile strength was 885.9 MPa (128.5 ksi) [1]. The total cross-sectional area of steel capillary tubing was 15.5 mm^2

($0.024\ in^2$) therefore the yield load was 871 kg (1,920 lbs) and the ultimate tensile load was 1,399 kg (3,084 lbs). Testing was performed to validate the deformation and failure point of the tubing. It was found that the tubing could hold a load of 1,302 kg (2,870 lbs) for a period of time before shearing and that there was little to no deformation.

The resistive forces that would be present during the installation were considered to determine the maximum amount of differential pressure that could be reached throughout the installation process. Based on past pigging experience and the designs for the pig shown in Section 2.2.6, it was estimated that the pig would require between 70-345 kPa (10-50 psi) throughout the installation. The resistive forces that were considered for the pilot project included the resistance of the sealing elements, the weight of the steel capillary tubing and the frictional forces of the steel capillary tubing caused by residual bending. It should be noted that calculations were not performed to determine the total drag of the steel capillary tubing while travelling through bends. This behavior was difficult to quantify without simulation software or physical testing so instead, conservatism was used to establish the maximum allowable differential pressure for the pilot project.

It was planned to pressurize the sealing elements to 172 kPa (25 psi) each to prevent gas from escaping the pipeline during the installation. In considering the cross sectional area of the steel capillary tubing, the resistance of the sealing elements was rather negligible at approximately 0.5 kg (1.2 lbs). As the pig travelled further down the pipeline, the weight of the steel capillary tubing would increase resulting in additional resistance on the pig. It was determined that once the pig reached the maximum installation distance of 800 m (2,625 ft), that the pig would be carrying approximately 95 kg (210 lbs) of weight. Lastly, the bending of the steel capillary tubing at the spool and at the guide arc would create residual stresses that would cause the tubing to bend when not under tension [2]. As the steel capillary tubing moved through the pipeline it was possible that it could touch the pipe walls which would increase the resistive forces on the pig. A frictional factor of 0.24 was used to account for the residual bending that would occur during the installation process. It was estimated that a load of 23 kg (50 lbs) would be created if residual bending occurred as the pig reached its maximum installation distance.

Thus, all three (3) resistive loads could total 120 kg (265 lbs) at any point in time, without including the drag that would be produced by the steel capillary tubing while traveling through bends. The maximum load that could be held instantaneously by the steel capillary tubing without deformation was found to be 1,302 kg (2,870 lbs) from the earlier testing. Therefore, it was possible that the steel capillary tubing could withstand a load of 1,182 kg (2,605 lbs) or 620 kPa (90 psi) of differential pressure during the installation. This differential pressure was higher than what was estimated to be required throughout the installation so it was decided that it was not a concern that the steel capillary tubing would fail.

Although the strength of the steel capillary tubing was acceptable for this pilot project, it may not be for all pipelines. As the pipeline size increases, so does the load exerted on the pig per square inch. For an NPS 12 pipeline with 6.4 mm (0.25 inch) wall thickness, the total load on the pig with a differential pressure of 165 kPa (24 psi) would exceed the tested steel capillary tubing failure point of 1,302 kg (2,870 lbs) without taking into consideration any of the resistive forces. In addition, pipelines with tight bends, multiple bends, large changes in wall thickness or large changes in elevation may require steel capillary tubing with a higher strength. It is recommended that each individual pipeline be studied prior to implementing the designs outlined in this paper so that steel capillary tubing with sufficient strength is sourced.

2.2.5 Disengagement System

The disengagement system was used to release the steel capillary tubing once the pig reached the maximum desired installation distance of 800 m (2,625 ft). It was important to design the disengagement system with the following in mind:

- The disengagement system must release the steel capillary tubing before the failure point is reached
- The disengagement system must be strong enough to withstand the differential pressures and resistive forces during the installation
- The disengagement system must activate at a differential pressure that can be reasonably reached once at the desired installation distance

It was decided to design the disengagement system to release the pig at a differential pressure of 524 kPa (76 psi). This differential pressure was lower than the 620 kPa (90 psi) that would damage the steel capillary tubing. It was also higher than the differential pressure that was estimated to be required throughout the installation (up to 345 kPa). Design details of the disengagement system are considered proprietary and will not be discussed in further detail for this paper.

2.2.6 Pig Design

The pig was designed to have four (4) sealing discs and three (3) guide discs spaced methodically throughout the 388 mm (15.3 inch) pig body. Two (2) sealing discs were placed in the front and back of the pig body as shown in Figure 4. Guide discs were placed at the front, middle and back of the pig. The sealing discs were made with a flexible durometer of 65º polyurethane to reduce the differential pressure required to launch the pig. The guide discs were made with a durometer of 85º polyurethane to provide the strength required to maintain centralization to the pig throughout the installation. The pig was sized to match the inside diameter of the line pipe with additional sealing surfaces to prevent surging[1] due to the low pressure/low flow envelope. The front of the pig was designed with a cavity for a transmitter so

[1] The term surging in this paper refers to the continuous stopping and starting of a pig as it moves through the pipeline.

that the pig could be located as required. The back of the pig was designed to contain the disengagement system.

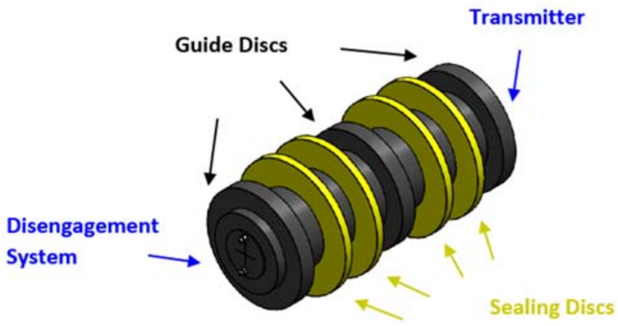

FIGURE 4: PIG DESIGN

2.2.7 Execution Plan

A low pressure/low flow envelope was ultimately decided upon to manage differential pressures in the line during the installation. At a lower pressure the chance for surging and large differentials would have existed, except for the fit for purpose design of the pig used. At this low operating envelope and with the design of the pig, it allowed for finite control of the tool while reducing the risk that the tool would build large differential pressure during stoppages that could have resulted in a premature disengagement of the steel capillary tubing. If the plan had been executed in a higher pressure envelope, the differential pressures during temporary tool stoppages would become more exaggerated and could easily succumb the disengagement design. It should be noted that performing this installation in a higher pressure envelope could be accomplished with design changes to the pig and disengagement system.

Nitrogen was injected into the pipeline prior to launching the pig to obtain a head pressure of approximately 414 kPa (60 psi). This would prevent the pig from surging during the installation and assist in maintaining control of the pig speed. It would also simulate a pipeline that was in operation. The target speed for the pig would be 1-1.3 m/s (3.3-4.3 ft/s) as this would be fast enough for the pig to travel smoothly through bends and wall thickness changes and also slow enough to maintain control of the rate at which the steel capillary tubing was installed. Pressure recorders were installed at the launch and receive sites to obtain information on the pipeline pressures throughout the installation.

Once the pipeline was pressurized and the gauges were installed, the pig was placed into the launching barrel. The steel capillary tubing was threaded through the pack-off hanger and the pack-off hanger attachment and connected to the disengagement system located at the back of the pig. Lubricant was applied to the pig to reduce the differential pressure required for launch and to assist with a smooth pig run. The pig was pushed into the pigging launcher as far as possible and the pack-off hanger attachment and pack-off hanger were bolted up to the pigging barrel as shown in Figure 5. The sealing elements were then pressurized to 172 kPa (25 psi) using a hydraulic hand pump. Nitrogen was injected into the pigging launcher to obtain a pressure of approximately 414 kPa (60 psi), equivalent to the pipeline's pressure. The isolation ball valve was opened and nitrogen injected into the kicker arms at a rate of 5 m^3 (177 ft^3) per minute. Once the pig was launched, the nitrogen injection was increased as required to achieve the target pig speed. Additional lubricant was added to the top of the pack-off hanger during the installation to reduce the frictional forces of the steel capillary tubing moving through the sealing elements.

FIGURE 5: LAUNCH SITE

The spool feeding the steel capillary tubing into the pipeline was held on the capillary injection unit as shown in Figure 6.

FIGURE 6: CAPILLARY INJECTION UNIT SIDE VIEW

A crane arm was used to hold the sheave wheel that fed the steel capillary tubing into the pack-off hanger as shown in Figure 7. The sheave wheel assisted in feeding the steel capillary tubing into the pipeline at the same 45º angle that the pack-off hanger was situated.

FIGURE 7: INJECTION UNIT FRONT VIEW

An encoder wheel was attached to the spool on the injection unit to measure the amount of steel capillary tubing injected into the pipeline and also the speed of the tubing leaving the spool. This assisted the operations crew in knowing when the installation distance of 800 m (2,625 ft) was reached so that the brakes could be applied to the spool. It also identified the speed at which the pig was moving in the pipeline and allowed for adjustments to be made to the injection of nitrogen. Once the distance and encoder wheel stated that about 750 m (2,460 ft) of steel capillary tubing had been injected, the nitrogen pump was slowed down so that the pig speed would decrease as it approached the maximum installation distance.

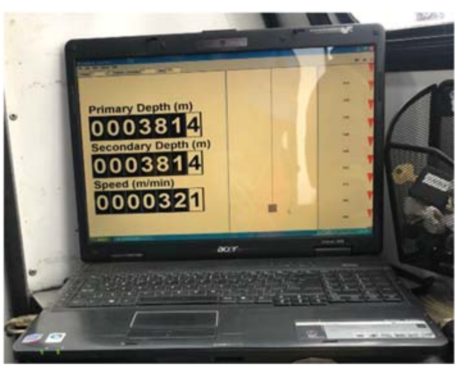

FIGURE 8: ENCODER WHEEL DISPLAY

Once the encoder wheel stated that 800 m (2,625 ft) of tubing had entered the pipeline, the brakes were applied to the spool. A knockout tank was used at the receive location to vent the nitrogen in the pipeline and create a pulling force to assist with activating the disengagement system. After the disengagement system was activated, the pig travelled to the receive site for removal from the pipeline.

The pressure on the sealing elements were increased to ensure that the pipeline could maintain pressure once put into service. The maximum operating pressure (MOP) of this pipeline was 6,205 kPa (900 psi) so the first sealing element was set to 20,684 kPa (3,000 psi) and the second was set to 13,790 kPa (2,000 psi). These values would be far below the maximum rating of 68,948 kPa (10,000 psi) for the sealing elements but also far above the pipeline's MOP. The carbon steel slips and thread protector were then installed on the pack-off hanger.

3. RESULTS AND DISCUSSION

Two (2) pigs were built for this pilot project so that a secondary pig was available if an issue occurred with the first. It was decided to run the contingency pig without the capillary tubing prior to attempting the installation to practice the execution plan and make any necessary adjustments. The pressure recorders were used to collect the pipeline pressures throughout the testing.

The test pig runs were performed on December 10, 2019. The weather was extremely cold with temperatures below -40ºC (-40ºF). The cold presented a challenge for the pilot project because it meant that the polyurethane pig would be rigid for the installation. A higher differential pressure would be required to launch the pig and achieving a controlled pig speed would be difficult. It was decided to set up hoarding and heating around the launch site to keep the equipment warm for the installation.

During the first test pig run there were some difficulties in identifying if the pig had launched from the pig barrel. Figures 8 and 9 show uneven pressures profiles at the launch and receive sites due to the interruptions caused by the launch issues. The differential pressure required to launch the pig was 180 kPa (26 psi) and the largest differential pressure seen was 215 kPa (31 psi) at the receive site. The total run time was approximately 23 minutes and the average pig speed was 1 m/s (3.3 ft/s)

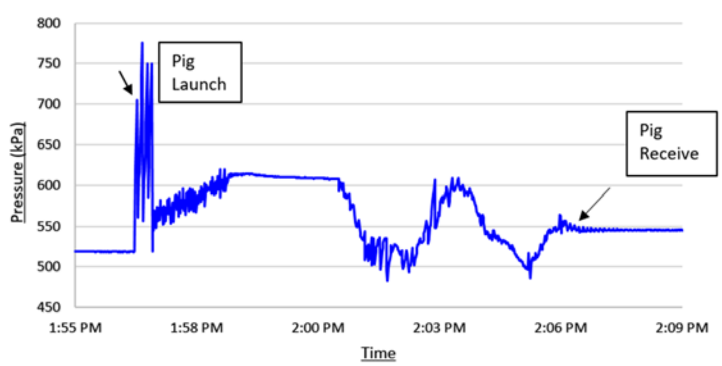

FIGURE 8: TEST #1 LAUNCH PRESSURE PROFILE

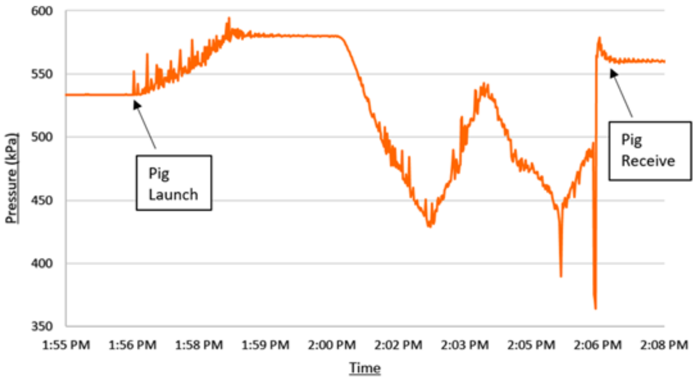

FIGURE 9: TEST #1 RECEIVE PRESSURE PROFILE

The field staff were confident that the pig left the launching barrel during the second test pig run and this shows in the pressure profiles in Figures 10 and 11 as they are consistent. The differential pressure required to launch the pig was 150 kPa (22 psi) and the largest differential pressure seen was 275 kPa (40 psi) at receive. The total run time was approximately 24 minutes and the average pig speed was 1 m/s (3.3 ft/s).

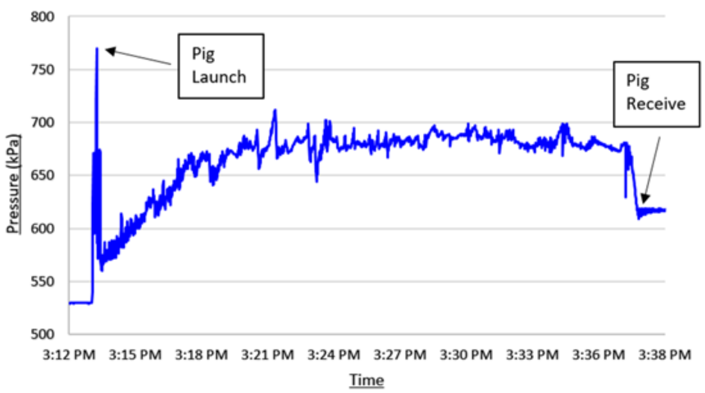

FIGURE 10: TEST #2 LAUNCH PRESSURE PROFILE

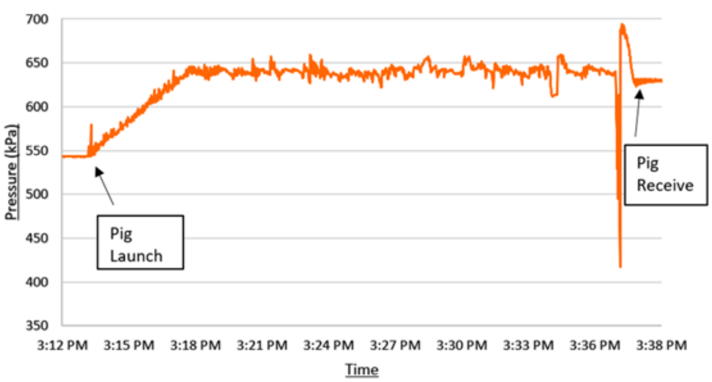

FIGURE 11: TEST #2 RECEIVE PRESSURE PROFILE

The results of the second test run showed that modifications to the execution plan were not necessary and that the team could move forward with the steel capillary tubing installation. The installation was performed on December 12, 2019. The tasks outlined in Section 2.2.7 were followed in preparation for the installation however it was forgotten to re-install the pressure recorder at the launch site. Therefore, pressure data was only available from the receive site as shown in Figure 12. The pig was launched with a differential pressure of about 290 kPa (42 psi) which meant that it required an additional 140 kPa (20 psi) to launch the pig once connected to the steel capillary tubing. Section A in Figure 12 shows the recorded pressures at receive as the pig traveled to the maximum 800 m (2,625 ft) monitoring distance. The end of Section A shows that the pig has reached the 800 m distance as there is a drop in pressure at the receive site. A pressure increase in Section B can be seen as the NPS 2 isolation valve leading to the knockout tank at the receive site was opened to increase the differential pressure across the pig. Nitrogen was injected at the launch site and all of the nitrogen between the pig and the receive site was vented to achieve the 524 kPa (76 psi) that was required to activate the disengagement system. It took approximately 30 minutes for the disengagement system to deploy. Section C shows the pressures at the receive site as the pig travels to the end of the pipeline. The installation was completed successfully.

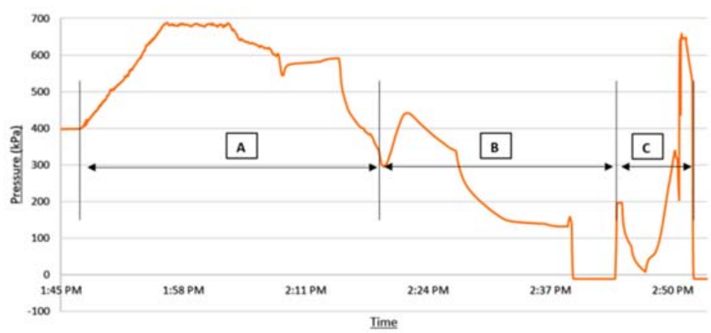

FIGURE 12: INSTALLATION RECEIVE PRESSURE PROFILE

4. MONITORING & FUTURE PLANS

An orientation was given to SaskEnergy Incorporated and TransGas Limited's operations staff to provide information on the pilot project and equipment that would remain on site for the one (1) year monitoring period. The steel capillary tubing was fed to a small 2.4 m x 4.9 m (8 ft x 16 ft) insulated trailer used to house the fiber optic monitoring system at the launch site. The pack-off hanger, pack-off hanger attachment, pigging launcher and steel capillary tubing would remain on site for the duration of the pilot project as well. The operations staff were required to incorporate the equipment left on site into their monthly station checks. A procedure was developed to highlight the key maintenance activities and response protocol.

The operations staff would be required to check the gauges on the pack-off seals during their monthly station checks. This included listening for leaks and identifying if any damage had occurred to the pack-off hanger or steel capillary tubing. The gauges on the sealing elements were expected to fluctuate with changes in outside temperatures. If the gauges showed a pressure below 6,895 kPa (1000 psi) then an immediate dispatch to site to increase the sealing element pressures would be required and a determination as to why the pressured reduction had occurred.

It was important that operations staff were aware that the isolation ball valve should not be cycled for the one (1) year monitoring period. Closing the ball valve would either damage the steel capillary tubing and fiber optic system or the ball valve itself. If the ball valve were damaged then it would not be possible to isolate the pigging barrel without blowing down the entire NPS 6 pipeline. Operations were also informed that pig runs on the pipeline would not be possible until the fiber optics were removed.

If an issue were identified with the pack-off hanger or other equipment on site, the operations staff have been instructed to report this immediately. In an emergency situation, removal of the steel capillary tubing from the pipeline would be required or the fiber optic system could be sheared using the ball valve.

The next phase of the pilot project will require baseline testing to program the monitoring network to events of interest. Notifications will be provided through a web-based control room interface as well as to mobile devices. The internal fiber optic system will be reevaluated after the one (1) year monitoring period is complete. At that time, it will be determined if the methods used in this pilot project will be applied for more time or on other pipelines in TansGas Limited's transmission pipeline system.

5. CONCLUSION

Fiber optic technology used for distributed pipeline monitoring can be installed into in-service pipelines using a pig, steel capillary tubing and a pack-off hanger. The methods used in this pilot project are most beneficial for pipelines that are located in areas where trenching is expensive or challenging to perform and an outage to the pipeline is undesirable. A disengagement system can also be incorporated into designs to control the amount of fiber optics required to monitor an area of interest. Developing fiber optic installation techniques is important to increase the number of pipelines that can feasibly use the technology.

The installation methods used in this pilot project were limited by the tensile strength of the steel capillary tubing. Individual pipelines should be analyzed prior to attempting the designs outlined in this paper to ensure that the steel capillary tubing will not fail during the installation. Operators should also keep in mind that the pipeline cannot be pigged while the steel capillary tubing is installed. The steel capillary tubing can be removed to perform pigging operators and re-installed afterwards. In addition, the pack-off hanger should be monitored regularly to ensure that the equipment is operating safely.

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